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Woods Hole, Massachusetts

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MARINE METEOROLOGY

WHOI Airplane Turbulence and Flux Measurements, O'Neill, Nebraska

August 21-28, 1953

By

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Director

WHOI AIRPLANE TURBULENCE AND FLUX MEASUREMENTS

O'NEILL, NEBRASKA, AUGUST 21 - 28, 1953

I. INTRODUCTION

The primary purpose of this report is to distribute data obtained over the plains of Nebraska to other participants of the Great Plains Turbulence Field Program at O'Neill. Little discussion or analysis of the data can be given until more data, such as the wind profiles obtained by other groups, are reduced and made available. A complete analysis will be contained in the final report of the Air Force Program.

The field program in which the marine meteorology group at Woods Hole was invited to participate was conceived and organized by members of the Geophysics Research Directorate of the Air Force Cambridge Research Center. They and their contract organizations interested in the study of atmospheric turbulence set up their equipment in an east-west line across a flat field near O'Neill, Nebraska. The site was chosen for its extreme flatness and the predominance of southerly winds during the summer months. Figure 1 is a photograph which shows the observing line and the flatness of the surrounding land. The ground stations were operated from August 1, 1953 to September 8, 1953. Woods Hole personnel operated only between August 21 and August 28. During this interval 56 horizontal runs were made between 40 ft. and 7000 ft. above the ground.

II. THE AIRPLANE TECHNIQUE OF MEASURING SHEARING STRESSES, ROOT-MEAN-SQUARE TURBULENCE VELOCITY COMPONENTS AND HEAT FLUXES

Only brief mention will be made here of the airplane method of measuring stresses and velocity components since the technique was described in WHOI Ref. No. 53-52. (About 20 copies of this report to the Office of Naval Research are still available.) It is planned to submit a revised copy of the report to a meteorological journal in the near future.

The method may be summarized as follows: All of the many qualifications, limitations, and difficulties of the system will be passed over in this statement. When an airplane flies through a turbulent atmosphere the angle of attack continually changes thereby modifying the lift of the airplane. If instruments are mounted in the airplane to measure the vertical accelerations of the airplane, the airspeed, and the attitude of the airplane, then the vertical velocity of any gust may be computed by placing the observed values in the following equation.

$$w_i = 4.98 \frac{\Delta n}{\rho V_t} - \frac{8.9 \times 10^3 \Delta V_t}{\rho \bar{V}_t^2} - \Delta\alpha_{att} V_t + \Sigma 1.1 \, \Delta n t_i - w_o \qquad (1)$$

Here w_i is the vertical component of the gust in cm/sec, Δn the observed vertical acceleration of the airplane, ρ the density of the air, V_t the true air speed, ΔV_t the deviation of the true airspeed from a line of regression upon time, $\Delta\alpha_{att}$ the change in attitude of the airplane, t_i the time interval of the measurement, and w_o the initial vertical velocity of the airplane. The coefficients in the equation depend on the mass of the airplane, its wing area and other considerations. Values of w' are obtained from the series of w_i's by eliminating any mean value of $\bar{w}_1$ and finding deviations from a line of regression of w_1 upon time. This step is necessary to eliminate the effect of any mean acceleration of the airplane, but it also eliminates the contribution of large eddies of the same size as the length of the observing run (1.5 km) to the shearing stress and root-mean-square velocity calculations.

The horizontal component of the gust velocity is obtained from the airspeed and the line of regression of the airspeed. Once the w_1 and u_1 values are obtained they may be combined to form the shearing stress, $-\bar{\rho}\,\overline{w'u'}$, and the root-mean-square velocities, $\sqrt{\overline{w'^2}}$, and $\sqrt{\overline{u'^2}}$. A thermocouple was mounted on the airplane so that deviations of the temperature could be combined with the w's to form $c_p\bar{\rho}\,\overline{w'T'}$, the heat flux.

Probable errors due to reading, calibrating, airplane deformation, instrumental inaccuracies, and symmetry assumptions are small. The errors arising from these causes based on 150 observational points amount to only ± 0.07 dynes cm^{-2} for the shearing stress, ± 1.7 cm sec^{-1} for $\sqrt{\overline{w'^2}}$, and ± 0.8 cm sec^{-1} for $\sqrt{\overline{u'^2}}$. These values are not, however, the total errors of the determinations. Phugoid motion (a vertical oscillation of the airplane of about 20 seconds period) can add up to +20 cm sec^{-1} to the root-mean-square velocities for an extreme case. In all cases presented here the oscillation was damped so that it is believed that this error does not exceed +5 cm sec^{-1}.

On August 25, 1953, the PBY flew past a tower on which Dr. Soumi had his sonic anemometer operating so a direct comparison of the two methods of determining $\sqrt{\overline{w'^2}}$ was made. The values obtained from the sonic anemometer mounted at 12 m were 72 and 68 cm sec^{-1} for the first and second run respectively. The PBY values were 58 and 60 cm sec^{-1}. The PBY value is based on a line of regression against time as described while the sonic anemometer is based on a mean value constant with time. When the PBY data is reduced in a comparable way 76 and 77 cm sec^{-1} are obtained for $\sqrt{\overline{w'^2}}$.

The agreement between the values obtained by such widely differing methods of measurements proves that the airplane method is reliable to at least 10% accuracy and probably better. A frequency diagram (Figure 2) of the vertical velocities obtained by the two methods is presented to show that the distributions are nearly the same.

III. EQUIPMENT MOUNTED IN PBY AIRCRAFT

The accelerations of the airplane were measured by a Statham electric accelerometer mounted near the center of gravity of the airplane. The output of this strain gauge bridge was recorded by one channel of a nine channel CEC oscillograph. For the air speed, the dynamic and static pressures of two pitot static tubes, one mounted on each wing, were connected to a single Statham differential pressure gauge to give an average value over the wingspread of the air speed. To record the attitude of the airplane a potentiometer circuit of an automatic pilot control was connected to the oscillograph. A reading of the attitude was made available to the pilot to enable him to keep the airplane at constant attitude. The thermopile was biased by two mercury cells and the resulting signal recorded on the oscillograph. The airplane's altimeter, airspeed indicator and flux gate compass were used for supplementary observations.

An airplane psychrograph was mounted on the side of the nose turret to give dry- and wet-bulb temperatures of the air. Rod thermistors are used in a bridge circuit as the sensing elements. The output of the bridge is recorded on an L and N Speedomax self-balancing potentiometer.

IV. FLIGHT PROCEDURE

A standard flight pattern was developed that would meet the requirements of (1) safety with regard to both ground personnel and other sounding aircraft, (2) non-interference with ground observations, and non-interference of ground equipment with air observations, and (3) an extended horizontal upwind course over terrain comparable to that upwind of the ground stations. A course that met these requirements was an upwind course of 2-3 miles extent with an end point 200 or 300 yds east and north of the eastern end of the observing line. A left turn was made at this point and the airplane climbed to the starting point of the course for another run. During the horizontal runs all the equipment was operating. The psychrograph was operated alone during the 200 ft per minute climbs to the next run level.

Two exceptions to the above flight pattern were made on August 25, when comparison tests were run with the sonic anemometer of the University of Wisconsin. For this test two passes were made past the instrument mounted at 40 ft on a tower. Actually, the flight was made higher than the instrument although it was intended to be at the same level. The passes were made upwind as usual and the instruments were operating both prior to arrival at the tower and for a minute or so after its passage.

No winds were measured by drift meter since so many wind observations were made by the ground stations.

V. PRESENTATION OF REDUCED DATA

Both the graphical and tabular forms are used in the presentation of the reduced data. Certain quantities that are related have been plotted on the same height diagram to clarify their relationship and allow the reader to get a complete picture of the variation of the quantities throughout the layer. The data is also tabulated for easy reference and extraction of exact values.

a) Psychrograph Data

Values of the potential dry-bulb temperature and the mixing ratio are collected in Table I. Not every value of the temperature and mixing ratio is given in the table. Rather, only enough significant levels are tabulated to show the variation with height and through the inversions. It will be noted that all available values have been plotted in the diagrams. The heights given in the table are heights in meters above the ground surface.

b) Turbulence and Flux Data

From the series of w_i, u_i and T_i obtained, the following quantities have been determined and entered in Table II. First, after an identifying run number and the height of the run above the ground, is the computed value of the shearing stress. It is found from the defining equation $\tau = -\rho \overline{w'u'}$ and the series of w_i and u_i values. In the next two columns are the values of $\sqrt{\overline{w'^2}}$ and $\sqrt{\overline{u'^2}}$. Next is the correlation coefficient between the w's and the u's. In the next column is the heat flux computed from $c_p \overline{\rho}\ \overline{w'T'}$. In the next column is the root-mean-square deviation of the dry-bulb temperature. In the last column a reliability indicator is entered. This key is based entirely on the change in attitude. If the attitude changed by less than $\pm 1^\circ$ the run is labelled, R, for reliable. If the attitude changed more than $\pm 1^\circ$, a U is entered indicating an unreliable run.

The data contained in Tables I and II have been plotted against height in seven diagrams, Figures 3 - 9. On the left is the potential dry-bulb

Psychograph Data O'Neill, Nebraska

TABLE I

A

Aug. 21, 1953
1112 to 1140 CST

Height m	Θd °C	w gm/kg
195	304.7	9.9
240	305.4	9.8
320	305.0	9.2
500	304.9	9.0
640	303.6	9.4
770	303.9	9.1
960	304.1	8.9
1110	304.2	8.5
1260	304.2	8.4

B

Aug. 22, 1953
1450 to 1540 CST

Height m	Θd °C	w gm/kg
35	307.2	7.8
65	307.2	7.8
100	307.3	7.7
165	307.3	7.4
285	307.8	7.5
480	308.2	7.2
700	307.6	7.4
900	307.5	7.2
1020	307.6	7.3
1110	307.4	7.4
1260	307.4	7.2
1495	307.0	7.3

C

Aug. 24, 1953
1547 to 1649 CST

Height m	Θd °C	w gm/kg
35	312.1	11.3
70	312.3	10.5
135	311.6	10.7
165	312.1	11.0
360	311.2	10.8
525	312.1	10.8
675	312.0	10.5
845	311.7	10.7
1155	311.6	10.3
1310	312.2	10.2
1565	311.9	10.2
1805	311.4	10.1
1950	311.5	10.0
2070	311.6	9.9
2130	312.2	8.8
2215	314.5	6.7

D

Aug. 25, 1953
1050 to 1150 CST

Height m	Θd °C	w gm/kg
35	307.4	Wick believed to be dry
65	307.2	
100	307.0	
130	307.0	
165	307.3	
210	307.1	
360	307.5	
490	308.7	
660	312.0	
825	311.9	
990	312.3	

E

Aug. 25, 1953
1600 to 1630 CST

Height m	Θd* °C	w gm/kg
180	312.6	Dry wick
360	312.6	
490	312.5	
660	312.5	
825	312.5	
1000	312.8	

*Temperature below 180 m off scale of psychograph

F

Aug. 27, 1953
1110 to 1211 CST

Height m	Θd °C	w gm/kg
35	308.2	13.3
65	308.0	13.5
100	308.5	13.5
130	308.1	13.5
165	308.1	13.4
330	308.6	13.3
490	308.5	13.2
660	308.5	13.1
820	309.0	12.9
990	309.0	12.6
1140	309.0	12.0
1170	311.2	10.3
1200	309.5	11.8
1260	311.6	10.0
1365	311.5	9.6
1540	312.9	8.5
1670	312.1	8.3

Psychograph Data O'Neill, Nebraska

TABLE I
(continued)

G

Aug. 28, 1953
1043 to 1145 CST

Height m	θd °C	w gm/kg
35	308.3	17.1
100	307.8	16.0
130	307.6	15.9
180	307.8	16.0
330	307.8	15.7
530	308.2	15.1
660	308.0	14.7
850	308.0	14.1
990	308.5	13.7
1140	312.4	12.0
1300	312.4	11.5
1500	313.4	11.9
1660	314.1	10.6

TABLE II

Turbulence and Flux Data

A

August 21, 1953 — 1012 to 1140 CST

Run No.	Altitude feet	Stress dynes cm^{-2}	$\sqrt{\overline{w'^2}}$ cm sec^{-1}	$\sqrt{\overline{u'^2}}$ cm sec^{-1}	r -	Heat Flux cal cm^{-2} sec^{-1}	$\sqrt{\overline{T'^2}}$ °C	Reliability
379	500	0.04	68	51	-0.01	0.0010	0.12	R
380	1000	1.4	86	49	-0.29	0.0005	0.09	R
381	2000	1.0	66	65	-0.22	0.0007	0.08	R
383	3000	-0.11	39	33	+0.06	0.0002	0.06	R
384	3500	0.26	52	35	-0.13	-0.0004	0.09	R

B

August 22, 1953 — 1450 to 1540 CST

Run No.	Altitude feet	Stress dynes cm^{-2}	$\sqrt{\overline{w'^2}}$ cm sec^{-1}	$\sqrt{\overline{u'^2}}$ cm sec^{-1}	r -	Heat Flux cal cm^{-2} sec^{-1}	$\sqrt{\overline{T'^2}}$ °C	Reliability
386	100	0.74	61	98	-0.11	0.0007	0.16	U
388	200	0.51	89	44	-0.14	0.002	0.18	U
389	500	-1.3	62	65	+0.29	-0.002	0.13	U
390	1000	1.16	97	86	-0.13	+0.002	0.15	R
392	2000	0.96	67	79	-0.16	0*	0*	R
393	3000	-3.05	82	71	+0.48	0*	0*	U
394	4000	-0.64	70	58	+0.14	0*	0*	U
395	5000	-0.99	76	66	+0.18	0*	0*	U

* not measured

C

August 24, 1953 — 1547 to 1649 CST

Run No.	Altitude feet	Stress dynes cm^{-2}	$\sqrt{\overline{w'^2}}$ cm sec^{-1}	$\sqrt{\overline{u'^2}}$ cm sec^{-1}	r -	Heat Flux cal cm^{-2} sec^{-1}	$\sqrt{\overline{T'^2}}$ °C	Reliability
398	100	-0.02	84	121	+0.002	+0.0017	0.17	U
399	200	1.2	89	97	-0.13	+0.0019	0.18	U
400	500	0.55	97	88	-0.06	+0.0017	0.13	R
401	1000	-1.3	56	48	0.44	+0.0004	0.054	R
402	2000	-0.13	63	45	-0.04	*	*	R
403	3400	1.9	120	99	-0.14	*	*	R
404	4000	-0.001	79	45	-0.0003	*	*	R
405	5000	2.05	57	60	-0.64	*	*	R
406	6000	-0.41	52	39	+0.18	*	*	R

TABLE II (continued)

Turbulence and Flux Data

D

August 25, 1953 — 1045 to 1115 CST

Run No.	Altitude feet	Stress dynes cm^{-2}	$\sqrt{\overline{w'^2}}$ cm sec^{-1}	$\sqrt{\overline{u'^2}}$ cm sec^{-1}	r -	Heat Flux cal cm^{-2} sec^{-1}	$\sqrt{\overline{T'^2}}$ °C	Reliability
410	100	3.11	77	109	-0.34	0.004	0.4	R
411	200	+3.32	92	73	-0.45	0.004	0.25	U
412	500	2.17	96	81	-0.25	0.001	0.11	R
413	1000	1.99	123	68	-0.22	0.003	0.13	R
414	2000	-0.16	19	15	-0.49	0.0002	0.013	R
415	3000	0.02	6	5	-0.57	*	*	
416	1900 to 2100	-1.0	84	78	+0.14	-0.001	0.93	U

E

August 25, 1953 — 1600 to 1650 CST

Run No.	Altitude feet	Stress dynes cm^{-2}	$\sqrt{\overline{w'^2}}$ cm sec^{-1}	$\sqrt{\overline{u'^2}}$ cm sec^{-1}	r -	Heat Flux cal cm^{-2} sec^{-1}	$\sqrt{\overline{T'^2}}$ °C	Reliability
418	3000	-0.78	85	65	+0.13	*	*	R
419	2000	-1.27	50	44	+0.53	*	*	R
420	1000	-0.09	37	33	+0.06	*	*	R
421	500	-0.20	58	45	+0.07	0.0006	0.055	R
422	200	1.82	70	70	-0.34	-0.0007	0.093	R
423	100	1.03	73	87	-0.15	0	0.08	U
424	40	1.9	58	103	-0.30	-0.0003	0.086	U
425	40	2.2	60	125	-0.41	0.0009	0.140	U

* not measured

TABLE II (continued)

Turbulence and Flux Data

F

August 27, 1953 1110 to 1140 CST

Run No.	Altitude feet	Stress dynes cm^{-2}	$\sqrt{\overline{w'^2}}$ cm sec^{-1}	$\sqrt{\overline{u'^2}}$ cm sec^{-1}	r -	Heat Flux cal cm^{-2} sec^{-1}	$\sqrt{\overline{T'^2}}$ °C	Reliability
429	100	-1.04	65	111	0.131	0.0015	0.25	R
430	200	+0.42	66	77	-0.08	0.0003	0.13	R
431	400-480	-0.59	58	54	+0.43	0.0010	0.13	R
432	900	-2.29	93	45	+0.50	0.0003	0.08	R
433	1900	+0.13	54	59	-0.04	0.0020	0.10	R
434	3000	-0.02	85	38	0.001	-0.0030	0.20	R
435	3700	-0.56	44	38	0.31	0.0023	0.30	R
436	4000	+0.34	58	36	-0.15	-0.0072	0.63	R
437	5000	+0.18	30	18	-0.29	0.0006	0.06	R
439	4000	-0.49	58	55	0.14	0.0003	0.26	R

G

August 28, 1953 1043 to 1136 CST

Run No.	Altitude feet	Stress dynes cm^{-2}	$\sqrt{\overline{w'^2}}$ cm sec^{-1}	$\sqrt{\overline{u'^2}}$ cm sec^{-1}	r -	Heat Flux cal cm^{-2} sec^{-1}	$\sqrt{\overline{T'^2}}$ °C	Reliability
441	100	+0.8	67	70	-0.17	0.0023	0.27	R
442	200	+3.3	121	67	-0.37	0.0050	0.26	R
443	500	+0.4	56	51	-0.14	0.0005	0.11	R
444	1000	-1.18	109	48	0.204	0.0044	0.21	R
445	2160	-4.13	104	79	0.512	0.0022	0.17	R
446	3000	-0.63	51	40	0.281	-0.00006	0.24	R
447	3400	-1.08	41	54	0.444	0.0010	0.62	R
448	4000	-1.68	47	45	0.721	0.0003	0.10	R
449	5000	0.14	24	15	-0.34	-		R

temperature. All values measured are plotted here instead of the few significant ones in Table I. The range in temperature observed on any horizontal run is indicated by a line with an "x" at either end. If there was an appreciable change in altitude the line is drawn sloping to indicate the altitude change. Similarly, the mixing ratios are plotted both as points and range lines. The shearing stress and the heat flux have been plotted with a common zero line. Different symbols and scales reduce confusion of elements. On the right, $\sqrt{\overline{w'^2}}$ and $\sqrt{\overline{u'^2}}$ are also plotted with a common zero line and different symbols. The only other entry on the diagram is a horizontal line drawn to delineate the inversion at the top of the ground layer. This inversion was not reached in all soundings.

Only very limited discussion can be made of the data until wind profiles are available. Many of the height variations of the stress values seem most peculiar and can only be interpreted later in conjunction with the measured winds. It is hoped that such huge swings as the stress took on the 22nd, 27th, and 28th will be explained by the winds. It is of interest to note that on only one day did the stress have a large, positive value near the ground and decrease more or less linearly to zero near the ground layer inversion. This distribution of stress values corresponds to the variation expected if the air under the inversion reacted as though it were a liquid confined in an open channel, an assumption frequently made in dealing with the atmosphere. This observation that open channel-like flow occurred when the inversion was relatively low may give a clue as to the role of the inversion height in defining a single flow pattern or stratification of the air into several distinct flow regions.

Values of $-\rho \overline{w'u'}$ taken in or near an inversion should not be interpreted as a stress or flux of momentum. This is true since the airplane frequently passes from one air layer to the other. Thus correlation between w' and u' may be computed that have little or no relation to the actual shear. Similarly, heat fluxes computed may be dependent more on the number of times the airplane crosses the boundary than on the flow of heat.

The variation of the values of $\sqrt{\overline{w'^2}}$ and $\sqrt{\overline{u'^2}}$ may be commented upon briefly. One point of interest is that the $\sqrt{\overline{u'^2}}$ is invariably greater than the $\sqrt{\overline{w'^2}}$ at the 30 m level, but at either the 60 or 100 m level the $\sqrt{\overline{w'^2}}$ becomes the larger. Above the 100 m level the values of both $\sqrt{\overline{w'^2}}$ and $\sqrt{\overline{u'^2}}$ are remarkably constant up to the vicinity of the inversion where they decrease rapidly to a small value. When values of the coefficient of turbulent mass exchange are computed it may be possible to determine the relation of the $\sqrt{\overline{w'^2}}$ to the coefficient without relying on an unobservable mixing length.

No spectrum analyses have been run upon the present series of data. The limitations of the system are such that only a rather narrow spectral band could be investigated. The smallest averages of significance may be defined as either 10 or 20 m eddies while the largest are of the order 1000 m. Spectral analysis within these limits may be carried out with assurance of significance.

Acknowledgements

The author wishes to acknowledge the large part that Kenneth McCasland played in the success of the enterprise. He not only designed and constructed the control circuits for the recording system, but skillfully ran the oscillograph and its associated instruments during the observational runs.

All of the shearing stress and root-mean-square velocity computations were made by Miss Martha Walsh.

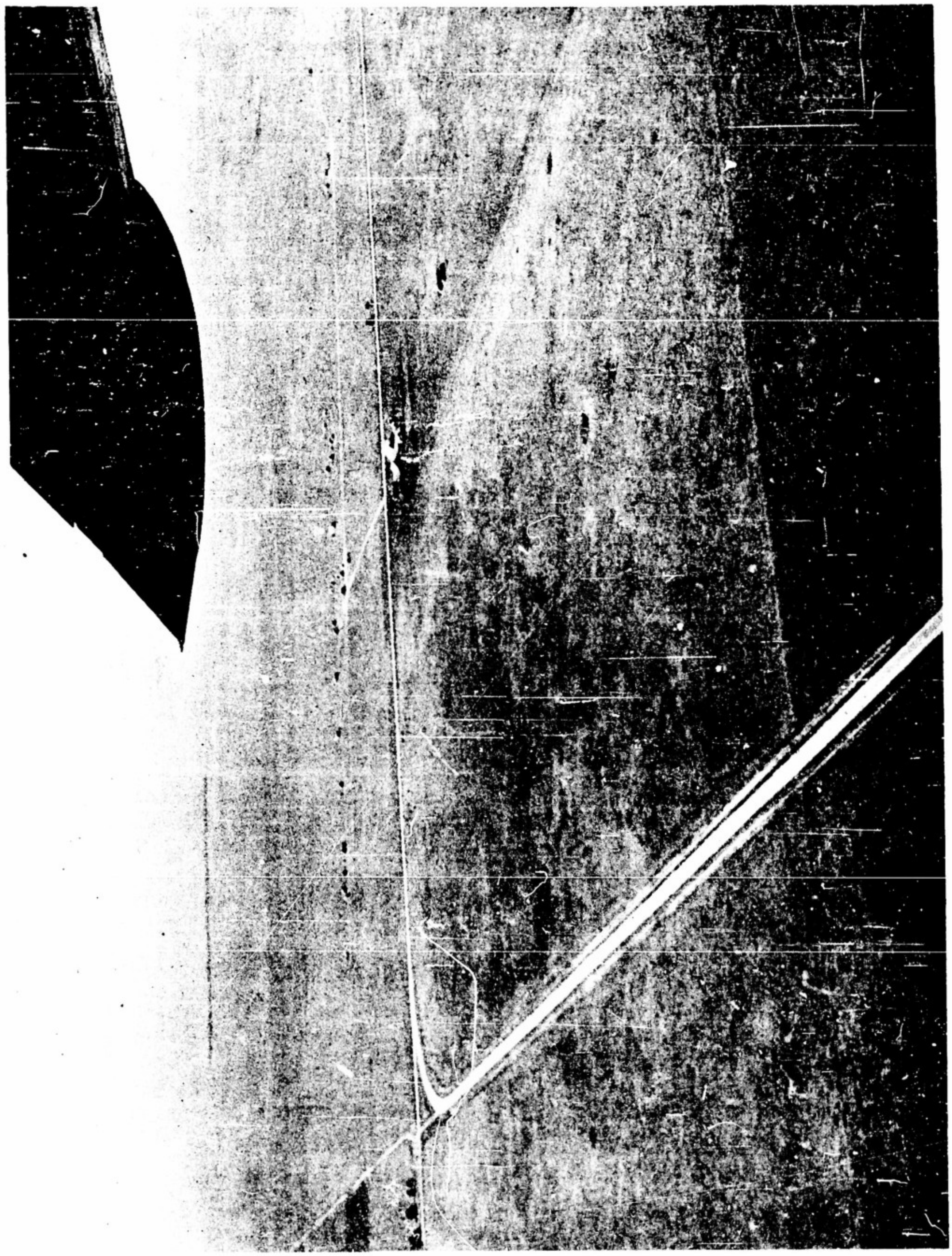
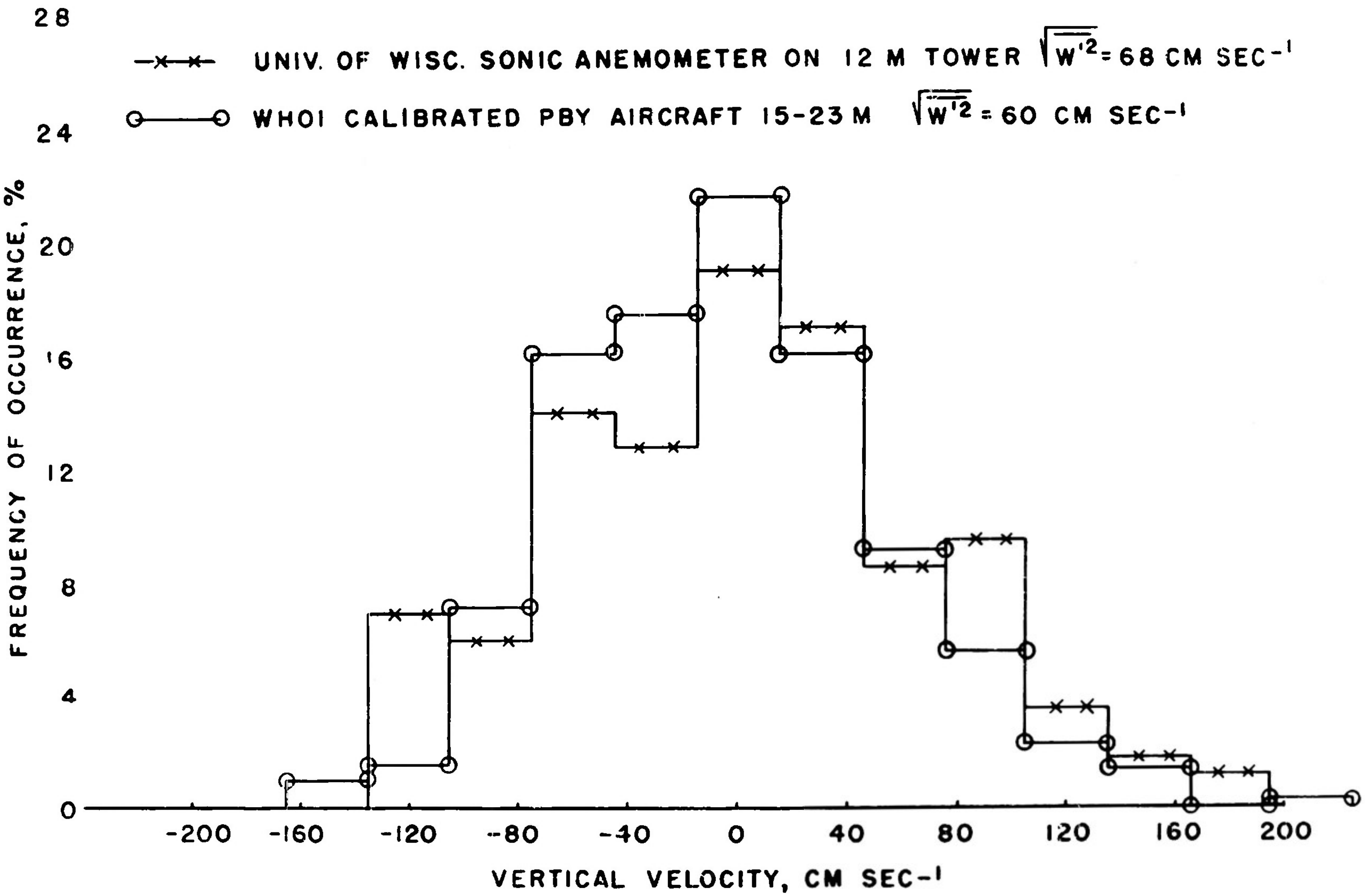


FIG. 1



AUG 25 1953 - 1645 HRS CST - O'NEILL, NEBRASKA

FIG. 2

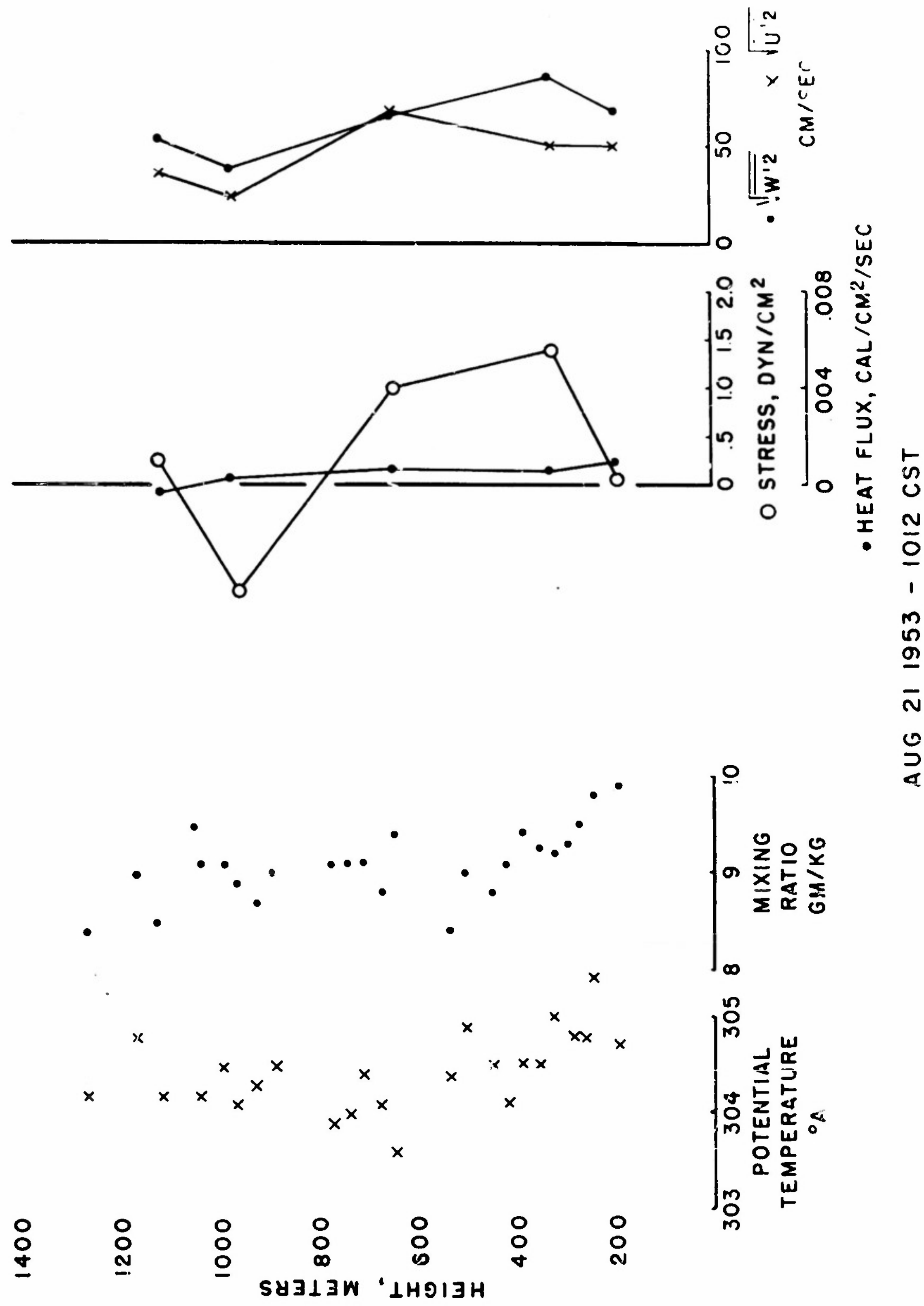
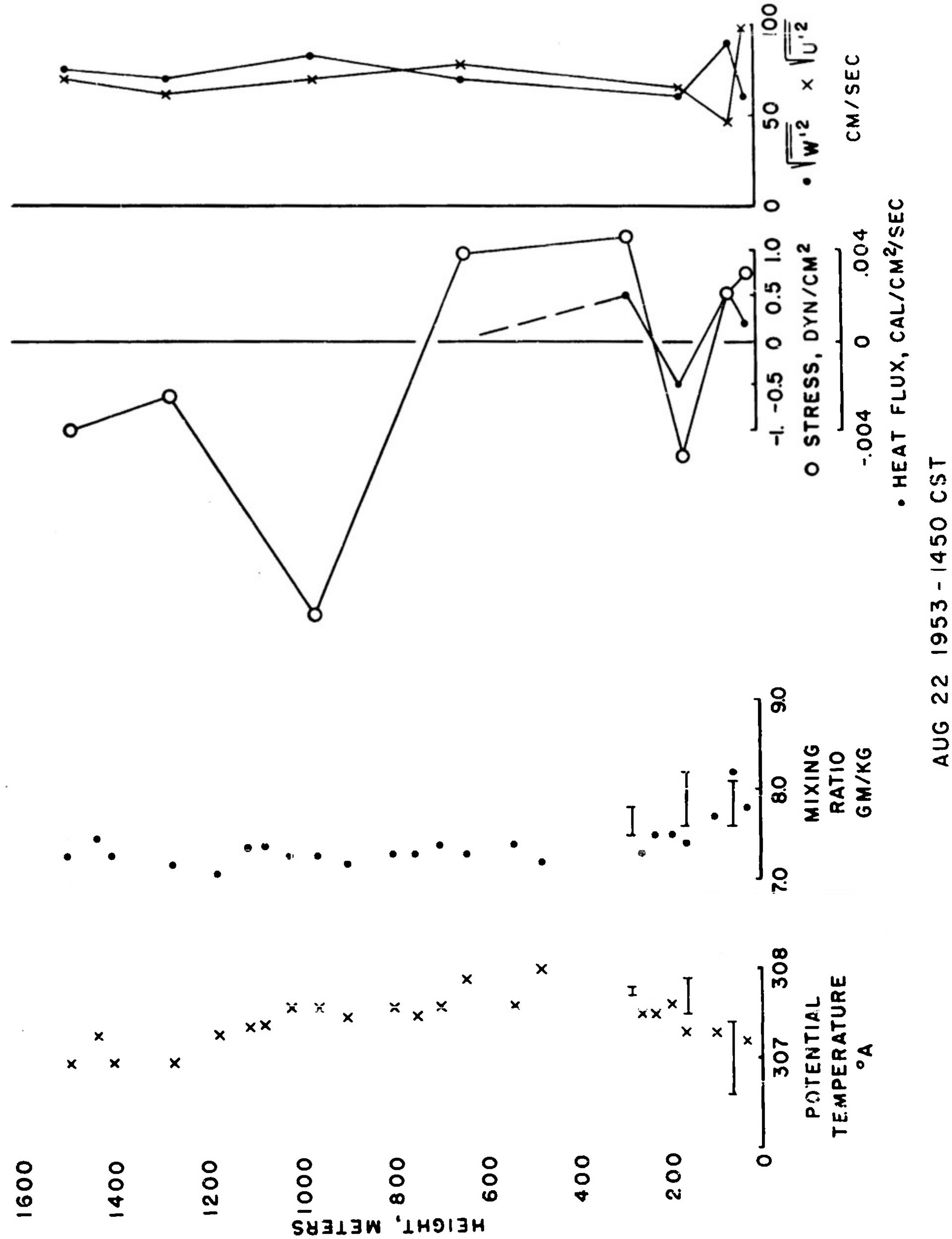
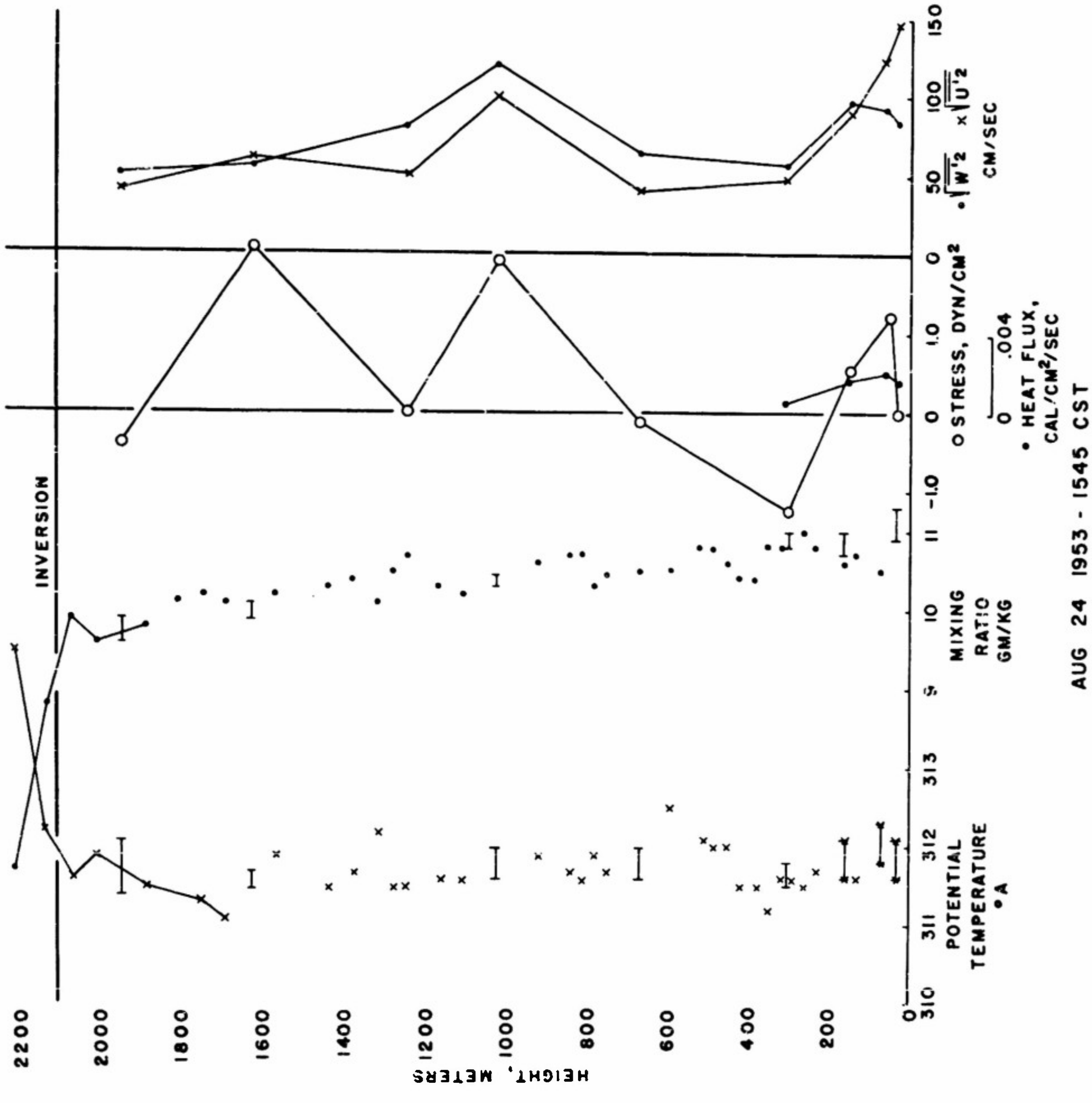

HEIGHT, METERS
1400
1200
1000
800
600
400
200
303
304
305
POTENTIAL TEMPERATURE °A
8
9
10
MIXING RATIO GM/KG
0
.5
1.0
1.5
2.0
O STRESS, DYN/CM²
0
.004
.008
• HEAT FLUX, CAL/CM²/SEC
0
50
100
• $\sqrt{\overline{w'^2}}$ × $\sqrt{\overline{u'^2}}$
AUG 21 1953 - 1012 CST

FIG.3



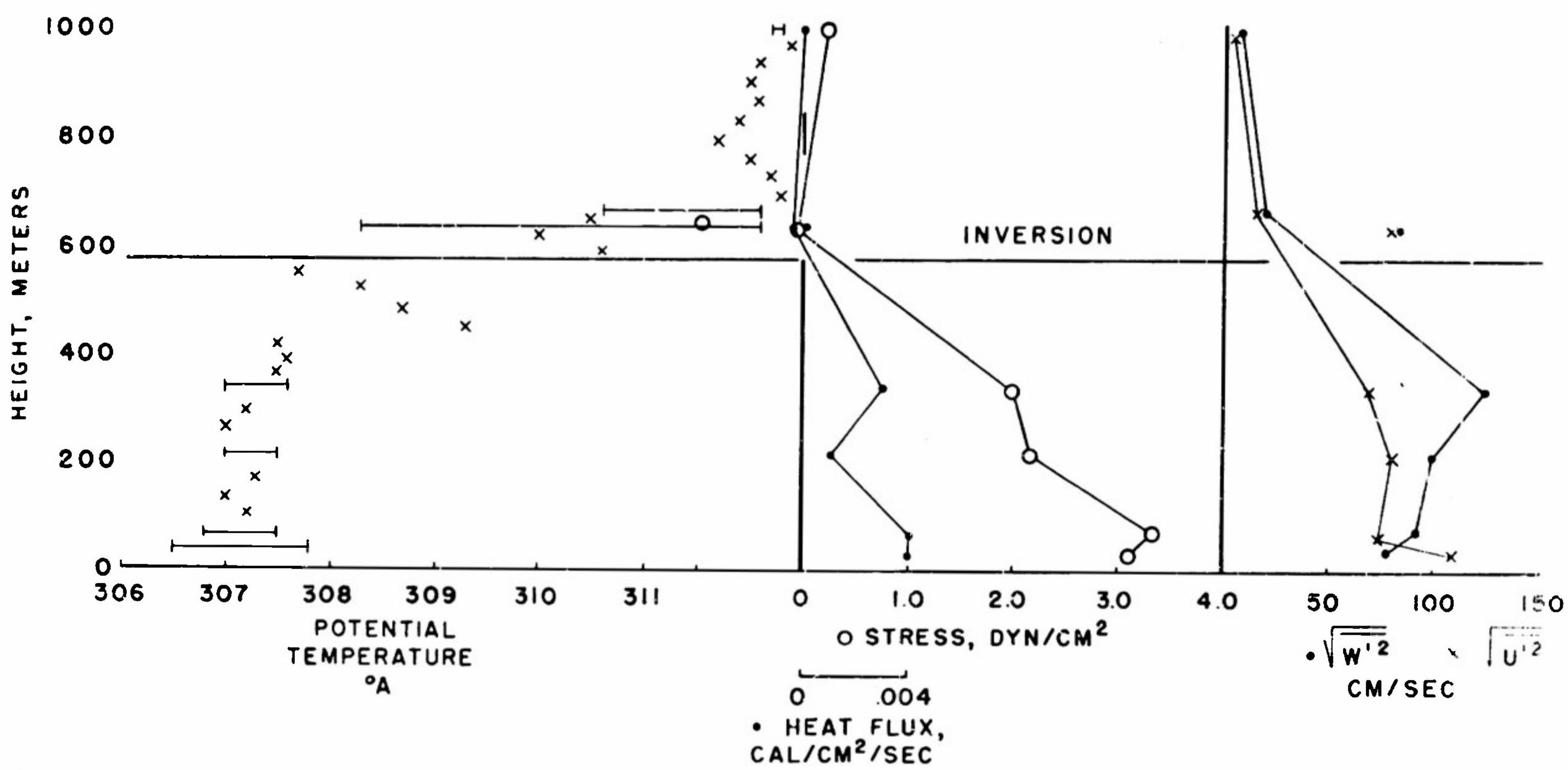
AUG 22 1953 - 1450 CST
HEIGHT, METERS
0
200
400
600
800
1000
1200
1400
1600
307
308
POTENTIAL TEMPERATURE °A
7.0
8.0
9.0
MIXING RATIO GM/KG
-1. -0.5 0 0.5 1.0
O STRESS, DYN/CM²
-.004 0 .004
• HEAT FLUX, CAL/CM²/SEC
0
50
100
• $\sqrt{\overline{w'^2}}$ × $\sqrt{\overline{u'^2}}$
CM/SEC

FIG. 4



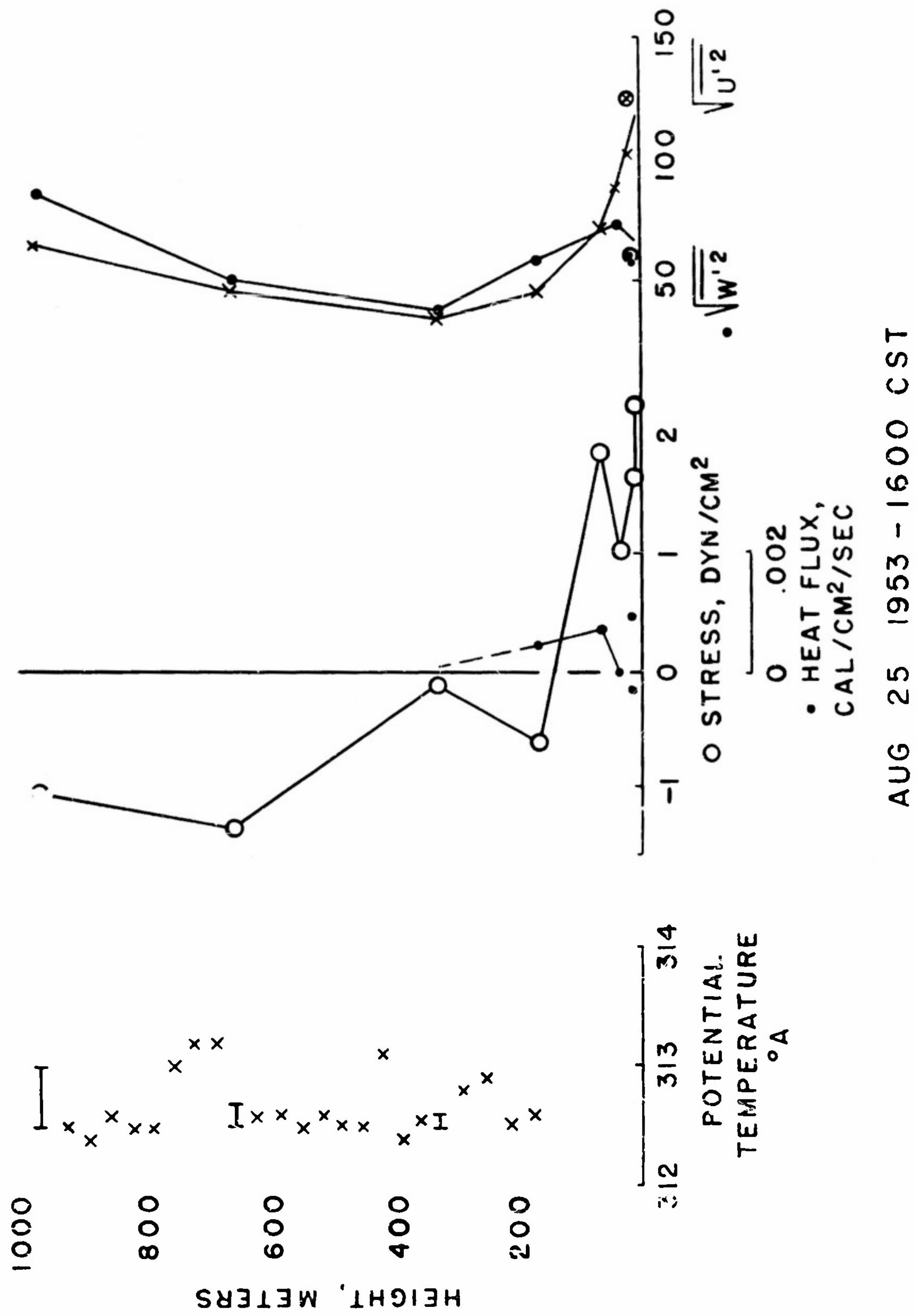
INVERSION
HEIGHT, METERS
POTENTIAL TEMPERATURE °A
MIXING RATIO GM/KG
○ STRESS, DYN/CM²
• HEAT FLUX, CAL/CM²/SEC
• $\sqrt{\overline{W'^2}}$ × $\sqrt{\overline{U'^2}}$ CM/SEC
AUG 24 1953 - 1545 CST

FIG. 5



AUG 25 1953 - 1100 CST

FIG. 6



HEIGHT, METERS
1000
800
600
400
200
312
313
314
POTENTIAL TEMPERATURE °A
-1
0
1
2
50
100
150
O STRESS, DYN/CM^2
0 .002
• HEAT FLUX, CAL/CM^2/SEC
• $\sqrt{\overline{W'^2}}$
$\sqrt{\overline{U'^2}}$
AUG 25 1953 - 1600 CST

FIG.7

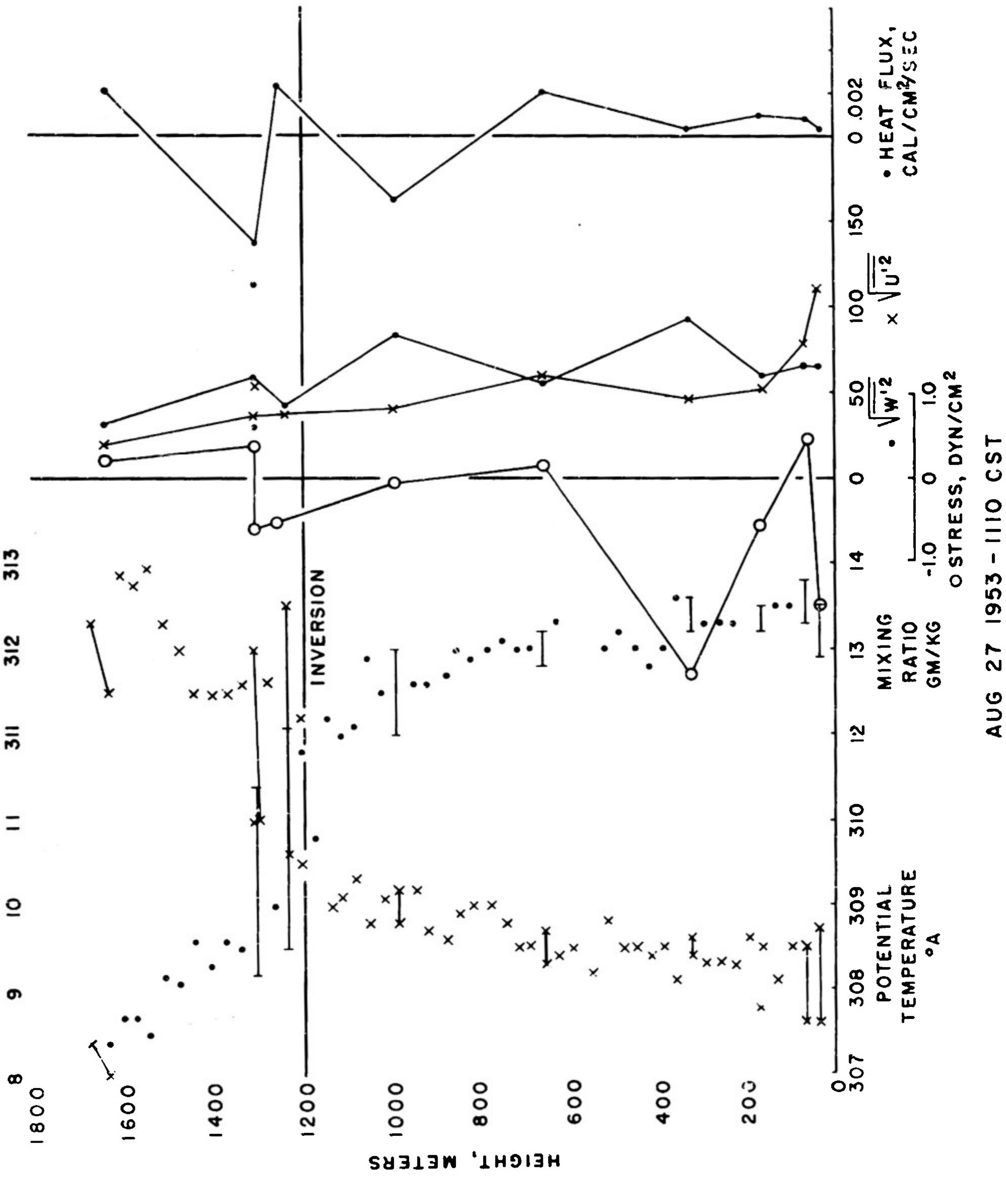
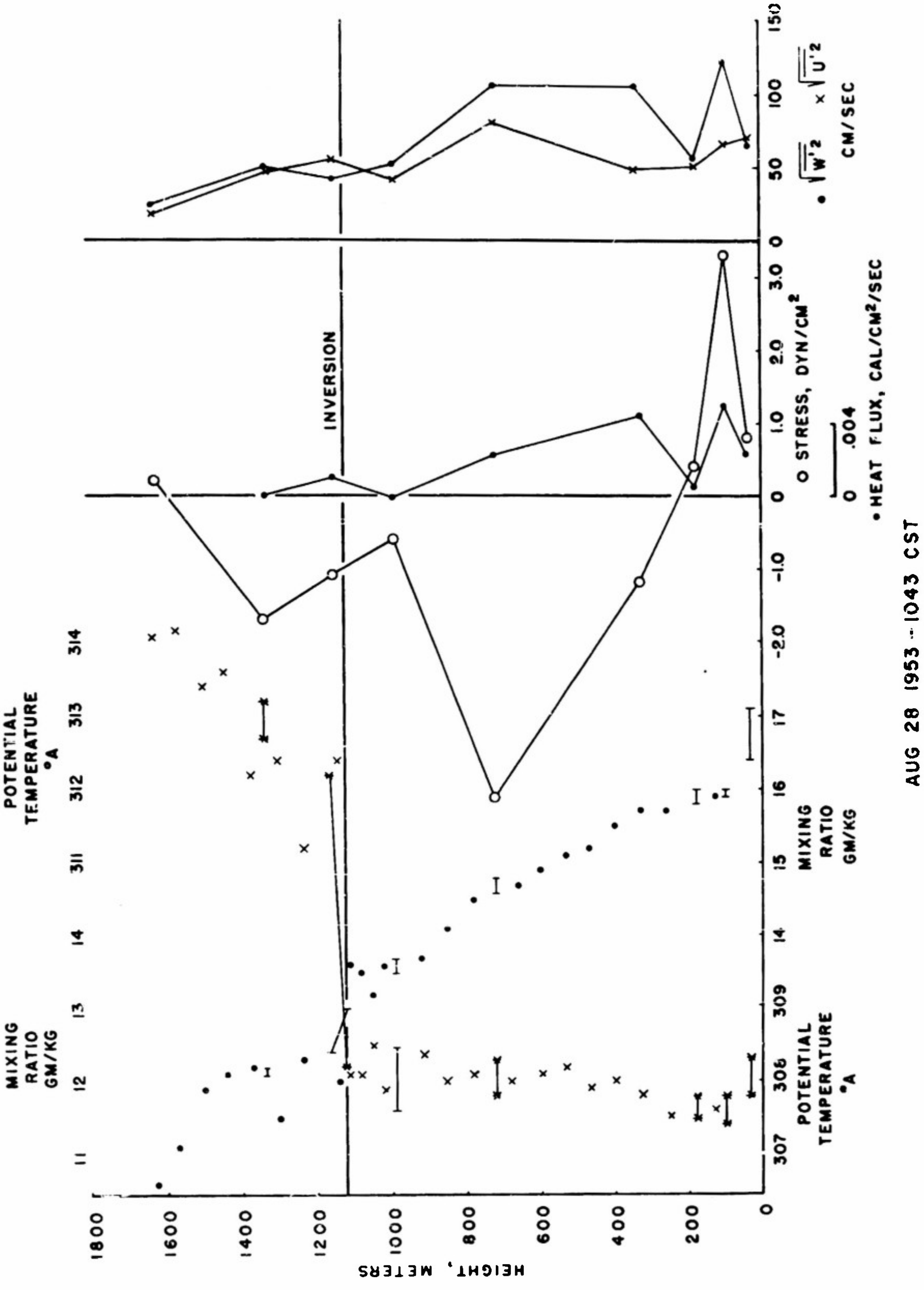

HEIGHT, METERS
INVERSION
POTENTIAL TEMPERATURE °A
MIXING RATIO GM/KG
○ STRESS, DYN/CM²
• $\sqrt{\overline{w'^2}}$
× $\sqrt{\overline{u'^2}}$
• HEAT FLUX, CAL/CM²/SEC
AUG 27 1953 - 1110 CST

FIG.8



MIXING RATIO GM/KG
POTENTIAL TEMPERATURE °A
INVERSION
HEIGHT, METERS
O STRESS, DYN/CM²
• HEAT FLUX, CAL/CM²/SEC
.004
• √w'² × √u'²
CM/SEC
AUG 28 1953 – 1043 CST

FIG.9

Legends for Figures

Figure 1. The flatness of the Nebraska plains can be judged from this photograph of the observing line at O'Neill.

Figure 2. The frequency distribution of the turbulent vertical velocities as measured by the sonic anemometer and the airplane are compared. The distributions are very similar.

Figure 3. Observations of stress, root-mean-square velocities, heat flux, potential temperature, and mixing ratio obtained over O'Neill, Aug. 21, 1953, 1012 to 1140 CST.

Figure 4. Observations of stress, root-mean-square velocities, heat flux, potential temperature, and mixing ratio obtained over O'Neill, Aug. 22, 1953, 1450 to 1540 CST.

Figure 5. Observations of stress, root-mean-square velocities, heat flux, potential temperature, and mixing ratio obtained over O'Neill, Aug. 24, 1953, 1547 to 1649 CST.

Figure 6. Observations of stress, root-mean-square velocities, heat flux, potential temperature, and mixing ratio obtained over O'Neill, Aug. 25, 1953, 1045 to 1145 CST.

Figure 7. Observations of stress, root-mean-square velocities, heat flux, potential temperature, and mixing ratio obtained over O'Neill, Aug. 25, 1953, 1600 to 1650 CST.

Legends for Figures
-continued-

Figure 8. Observations of stress, root-mean-square velocities, heat flux, potential temperature, and mixing ratio obtained over O'Neill, Aug. 27, 1953, 1110 to 1140 CST.

Figure 9. Observations of stress, root-mean-square velocities, heat flux, potential temperature, and mixing ratio obtained over O'Neill, Aug. 28, 1953, 1043 to 1136 CST.

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